Development of a Coupled Land Surface and Groundwater Model

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RESEARCH OBJECTIVES

Land-Surface Models (LSM), used for numerical weather simulation, climate projection, and as inputs to water management decisions, do not treat the LSM lower boundary in a fully process-based fashion. This lower boundary is often assumed to be zero flux, or the soil moisture content is set to a constant—an approach that while mass conservative, ignores processes that alter surface fluxes and water quantity and quality. Conversely, groundwater models (GWM) for saturated and unsaturated flow often have overly simplified upper-boundary conditions that ignore soil heating, runoff, snow, and root-zone uptake. The objectives of this study are to indicate a new approach and methodology for coupling a state-of-the-art CLM (Common Land Model) and a variably saturated GWM (ParFlow), and to replicate this study for CLM and the Berkeley Lab Earth Sciences Division GWM, TOUGH2.

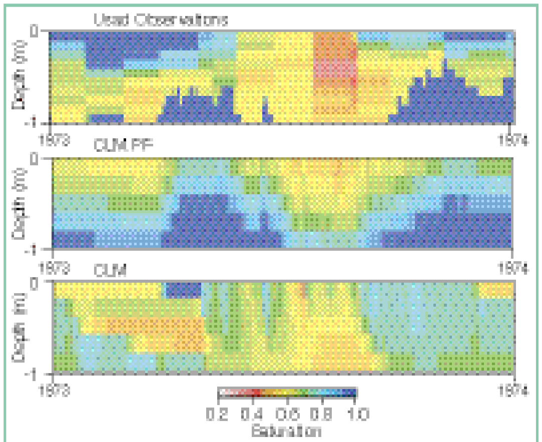

Figure 1. Plot of observed and simulated soil saturations for Valdai as a function of time and depth for 1973. Average soil moisture observations for the Usad catchment are plotted in the first panel, with CLM.PF model simulations in the middle and CLM simulations at the bottom. Note that only the first 1 m of model simulations are plotted to match the observations. Note also that the solid blue regions denote completely saturated conditions where the WT depth is less than one meter.

APPROACH

The water-balance equations represent the link between the LSM and the GWM. The CLM and ParFlow models were coupled at the land surface and soil column by replacing the soil column/root zone soil moisture formulation in CLM with the ParFlow formulation. All processes within CLM, except for those that predict soil moisture, are preserved within the original CLM equations.

The coupled model, CLM.PF, communicates over the 10 soil layers in CLM, with the uppermost cell layer in ParFlow. Soil saturation is calculated from the hydraulic pressure solution over the entire domain, with the water content at the upper ten layers passed back to CLM, where soil surface temperatures, heat fluxes, and energy balances are calculated.

ACCOMPLISHMENTS

Simulations for both the coupled (CLM.PF) and uncoupled (CLM) models are compared to the Usad Watershed observations. The simulations of sensible heat flux and evapotranspiration for the coupled and uncoupled models agree closely. However, the runoff rates are more accurately simulated by the coupled model, with the uncoupled model tending to underestimate the observed flow rate. The differences in runoff result from the explicit simulation of the water table (WT) in the coupled model.

The three plots of soil saturation provide insight into the differences in model simulation and agreement with observations. Shallow simulations (20 cm) show that soil saturation for the coupled and uncoupled models are very similar, particularly during the summer months. This corresponds to the similarities in the simulated evapotranspiration between the two models. Deeper simulations of soil saturation (40 cm and greater) are quite different; with the coupled model agreeing well with observations (see Figure 1). CLM.PF stores water in the subsurface, and includes a memory effect on model behavior that extends beyond seasonal time cycles. This effect can be seen in the figure, where WT storage and soil moisture memory affect other modeled processes.

SIGNIFICANCE OF FINDINGS

CLM.PF behaves much differently from CLM and expands the capabilities of the groundwater model to include land surface processes. CLM.PF provides simulations of the subsurface, which, because of the explicit accounting for water up to and below the WT, have a memory of water stored in the deep subsurface. The simulations presented here show that this scheme balances mass across the land surface/groundwater boundary and provides new insights into coupled processes. The coupled model also has a different depiction of the root-zone soil moisture than the uncoupled model, leading to more realistic behavior that more closely matches observations at the Usad site. The coupled model demonstrates the need for better groundwater representation in land surface schemes. This study has been duplicated for CLM and TOUGH2 with similar results, and we expect to use this for new applications.

RELATED PUBLICATION

Maxwell, R.M., and N.L. Miller, Development of a coupled land surface and groundwater model. Journal of Hydrometeorology, 6 (3), 233–247, 2005. Berkeley Lab Report LBNL-55029.

ACKNOWLEDGMENTS

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